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Berger

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[54] **MODIFIED PRESTRESSED MEMBRANE STRUCTURE**

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[51] **Int. Cl.** **E04b 1/347**
[58] **Field of Search** .... 135/1 R, 3 R, 4 R, 135/5 R; 52/63, 80

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[57] **ABSTRACT**

A shelter structure has a plurality of rigid inverted V-shaped frame members positioned in a predetermined array forming a closed polygon when viewed in plan. A relatively rigid compression member operatively interconnects the apices of each of the inverted V-shaped frame members and a flexible membrane is supported within the frame members, conforming in plan to the closed polygon defined thereby. A first set of prestressed tension cables, operatively connected to the apices of the inverted V-shaped frame members, support the flexible membrane. A second set of prestressed tension cables are secured to the inverted V-shaped frame members and operatively associated with the membrane in predetermined positions between the first set of cables in order to maintain the membrane in tension under substantially all load conditions. As a result, the first and second sets of prestressed cables will cooperate with each other and with the flexible membrane to form a relatively rigid and stable structure.

17 Claims, 4 Drawing Figures

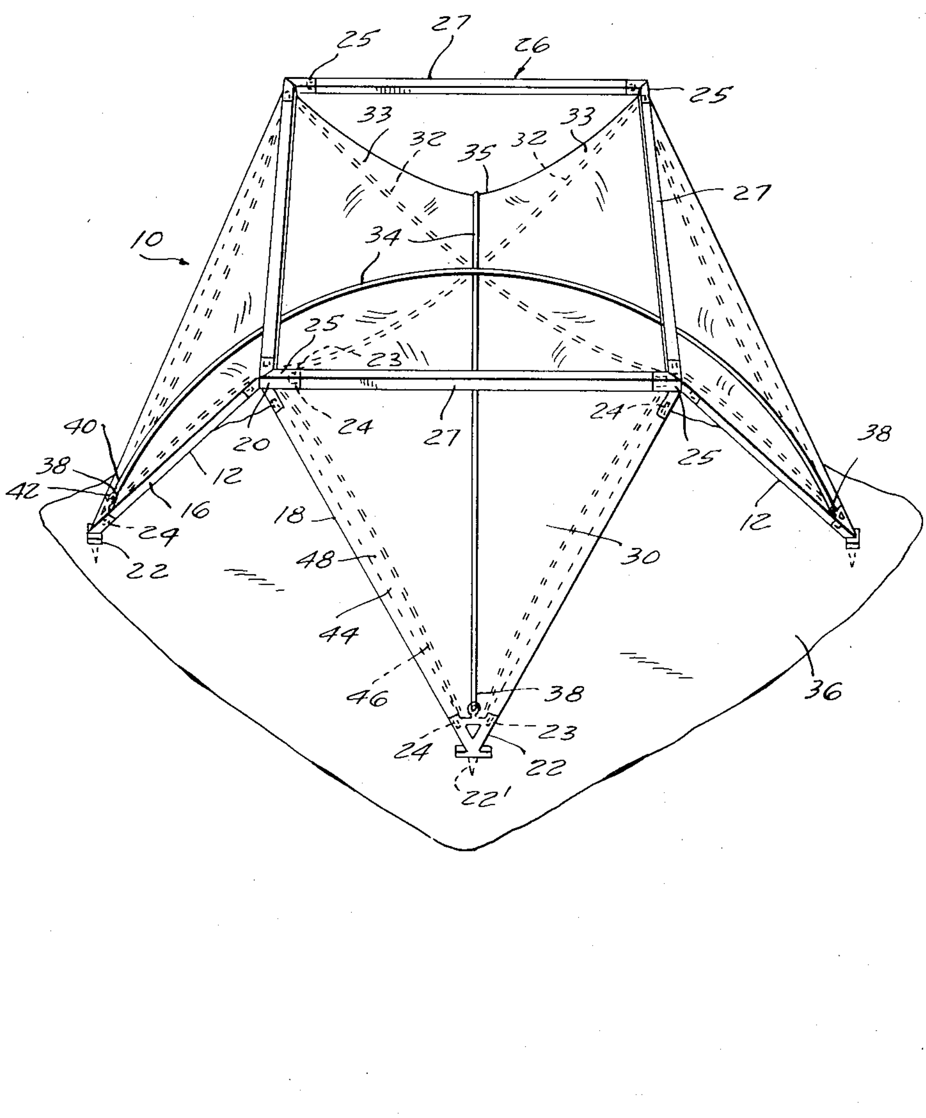

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FIG. 1

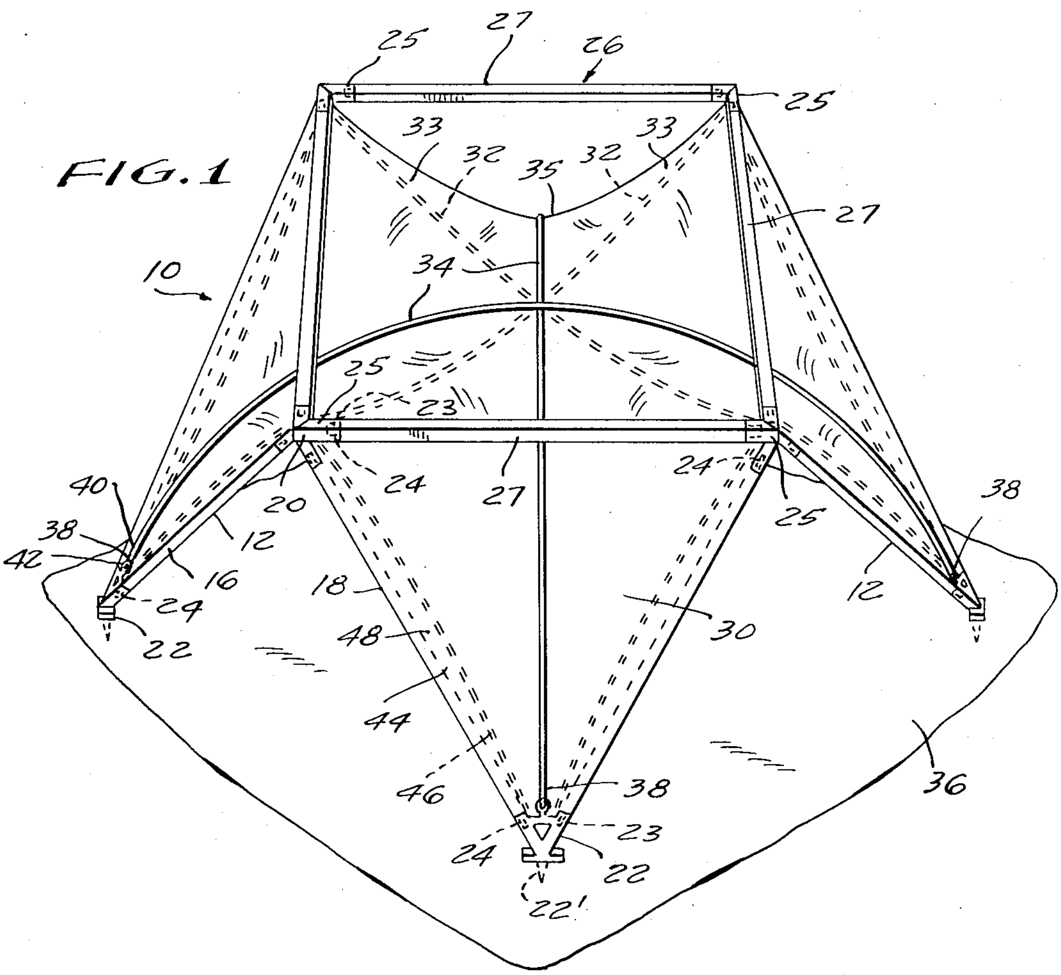

FIG. 3

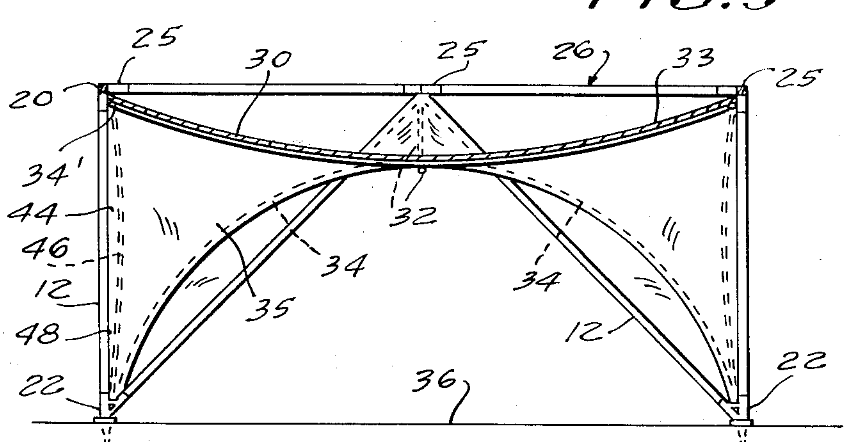

FIG. 2

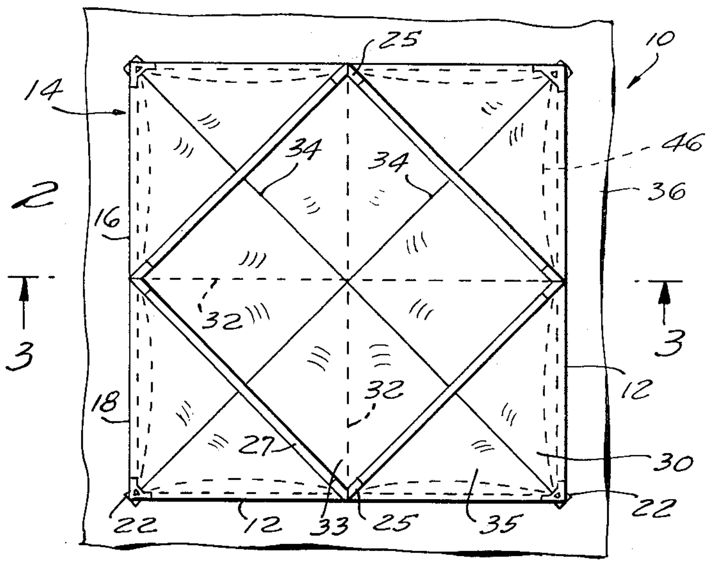
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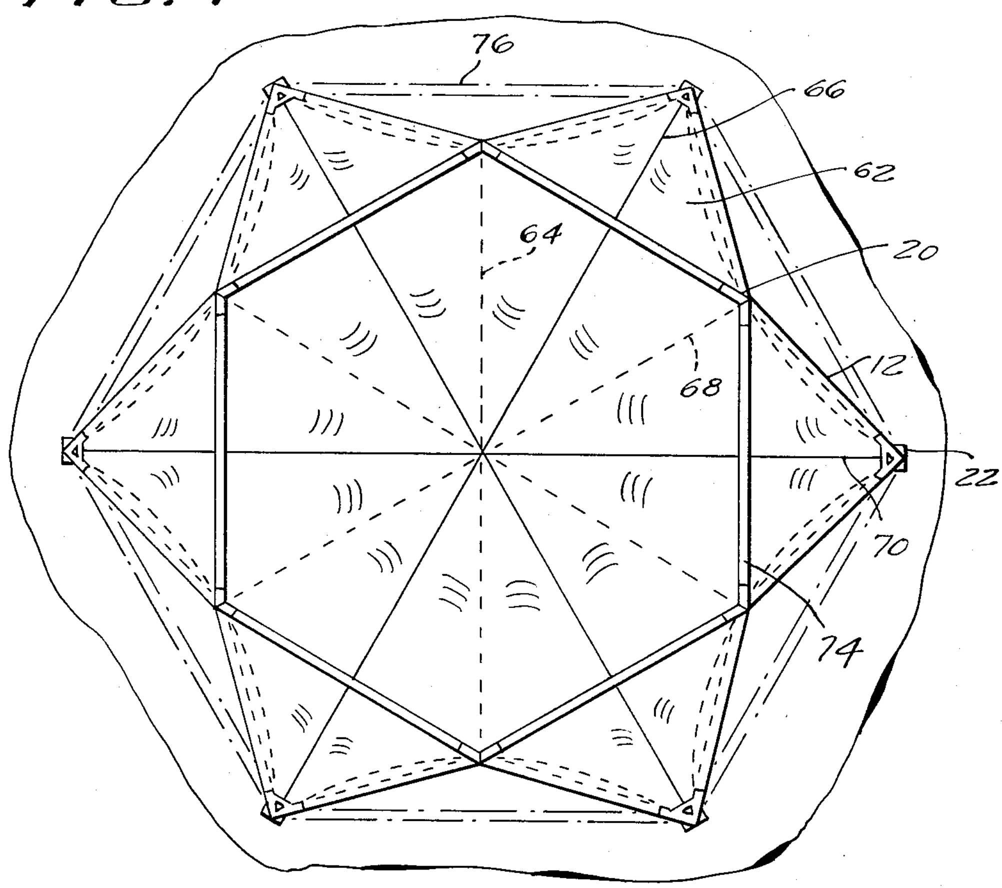
FIG. 4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MODIFIED PRESTRESSED MEMBRANE STRUCTURE

The present invention relates to a building structure or shelter and more particularly to a structural system suitable for use as a temporary or permanent enclosures and shelters of various sizes.

There has recently been an increased demand for inexpensive housing and shelter structures due to the increased cost of labor and material required for erecting previously proposed types of buildings. Moreover, this demand includes a need for flexible building structures which can be readily converted from temporary to permanent usage and which are readily assembled and maintained. Such structures are often desired for use as temporary vacation homes, buildings or schoolrooms and emergency shelters.

In previously proposed building structures of both the temporary and permanent type, some or all of the structural components utilized are relatively heavy wooden or steel members which serve to provide the structural stability of the building. Such members normally account for a substantial portion of the cost of the building structure and are relatively difficult to transport from the fabrication plant to the building site. As a result, temporary shelters, particularly emergency shelters for use in hurricane or earthquate disasters or the like are both relatively expensive and difficult to transport to the required location. Moreover, such previously proposed shelters have not been entirely satisfactory for use as temporary vacation homes or shelters since they are difficult for the individual to transport and erect and typically require specialized equipment or tools and a large number of laborers.

Accordingly, it is an object of the present invention to provide a relatively simply constructed and erected structure which is both economical in manufacture and in use.

Another object of the present invention is to provide a building structure which is readily erected and converted from emergency or temporary shelter to a permanent use.

Yet another object of the present invention is to provide a building structure or system which is suitable for a number of uses including that of temporary shelter which is adapted to be transported to the erection site in an individual's private car or vehicle and erected by one or two persons.

In accordance with one aspect of the present invention, a temporary shelter or building is provided in which a plurality of inverted V-shaped rigid frame members are positioned on a common support in an array forming a closed polygon, which, in the preferred embodiment of the present invention forms a square or other regular polygon when viewed in plan. A flexible, relatively non-stretchable membrane is operatively associated with the frame members and, preferably, is contoured to form ridges therein extending between the apices of the rigid frame members with valleys being formed therebetween. A first set of prestressed tension cables are operatively connected between the apices of the frame members and support the flexible membrane along the ridge lines therein. A second set of prestressed tension cables is also operatively associated with the membrane and connected to the frame members, with at least one cable in the second set being located in each of the valleys of the membrane between adjacent pairs of cables in the first set.

A rigid compression member interconnects the apices of the inverted V-shaped frame members to resist the forces applied to these frame members by the prestressed cables which would tend to collapse the frames inwardly. As a result of this construction, the first and second sets of prestressed cables cooperate with each other and with the membrane to prestress the membrane and form, with the various frame members, a relatively rigid self-supporting structure.

As will be described more fully hereinafter, the structure of the invention is relatively simple to erect because of the light weight of the various components and the flexible nature of the membrane used therein. Accordingly, the structure is readily erected at an emergency site, for use as a temporary emergency shelter. Moreover, the lightweight components utilized to form the structure are readily transportable so that the structure is extremely economical for use in emergency situations and quite suitable for home use; for example, as a temporary vacation home or as home tennis court shelters and the like.

The above, and other objects, features and advantages of this invention will be apparent in the following detailed description of an illustrative embodiment thereof which is to be read in connection with the accompanying drawings, wherein:

FIG. 1 is a perspective view of a shelter structure or building constructed in accordance with one embodiment of the present invention;

FIG. 2 is a plan view of the structure illustrated in FIG. 1;

FIG. 3 is a sectional view taken along line 3—3 of FIG. 2; and

FIG. 4 is a plan view similar to FIG. 2 of another embodiment of the invention.

Referring to the drawing in detail, and initially to FIG. 1 thereof, it is seen that a building structure or shelter **10** embodying the present invention, is formed from a plurality of relatively rigid inverted V-shaped structural members **12**, arranged with respect to each other to form a closed polygon which, in the illustrative embodiment of the invention, describes a square **14** as seen in FIG. 2.

In the preferred embodiment of the invention, inverted V-shaped frame members **12** are formed from a pair of separate leg members **16, 18** which are connected at their apex **20** in any convenient manner. The lower ends of the legs are secured in base members **22** which also form the base for one leg of the next adjacent inverted V-shaped member. These base members are secured to a common support **36** in any convenient manner. For example, where the structure is erected on the bare ground, conventional earth anchors **22'** are secured to the base members for maintaining the base members in the ground in a relatively fixed position.

Legs **16** and **18** are preferably cylindrical or rectangular hollow tubes having extensions **24** at their free ends which are conveniently inserted within complementary sockets **23** formed in the base members **22** and apex connector **25** in order to form a rigid structural arrangement.

The apex of each of the inverted V-shaped structural members **12** are interconnected by a relatively rigid compression structure **26** which, in the illustrative embodiment, is formed in a generally rectangular configuration. Compressive structure 26 is similarly formed of cylindrical or rectangular hollow tubular members 27 having extensions 24 at their ends which are received in complementary sockets in apex connectors 25. For temporary shelters the frictional engagement between legs 16, 18 and structural members 27 of compressive structure 26 in the sockets of base members 22 and connector 25 is sufficient to maintain the stability and configuration of the building. However, for more permanent structures, these connections may be made permanent by the use of bolts, fastening pins, or any other convenient connection system.

The skeleton frame system defined by inverted V-shaped members 12 is covered by a flexible membrane 30 which is positioned within the framework and operatively connected to legs 16, 18 more fully described hereinafter. Preferably, membrane 30 is formed from any convenient material which is relatively flexible and strong yet elastically stretchable. In addition, the membrane is manufactured to have a predetermined contour having ridges and valleys formed therein to cooperate with the prestressed cables used in the structure. However it is contemplated that the membrane may be non-contoured and simply secured to the cables as described hereinafter. In either case, the configuration of the membrane when viewed in plan corresponds to the polygonal shape defined by the peripheral inverted V-shaped members 12, in the manner illustrated in FIG. 2.

Membrane 30 is supported on the frame structure by two sets of cables 32, 34. Cables 32 are operatively connected between opposed apices 20 of the structure, in any convenient manner, although, in one embodiment, the cables may be provided with hooks on their ends which can be connected in eye members (not shown) secured to apex connectors 25.

Membrane 30 may be connected to cables 32 by a sleeve (not shown) formed in the membrane and receiving the cables, or alternatively, the cables may be sewn into the fabric forming membrane 30 or may be simply frictionally engaged with the fabric by placing the fabric on top of the cables as seen in FIG. 1. In either case cables 32 serve to support the membrane above the ground or common support 36 upon which the structure is seated. Where there is no direct physical connection of the cables to the membrane, the membrane itself may be provided with hooks on its corners adjacent connectors 25 so that it can be secured to eyelets (not shown) in the same manner as the cables.

In the preferred embodiment of the invention cables 32 have a predetermined length so that in the completed structure they will be prestressed, for reasons more fully described hereinafter. Alternatively the cables may be provided with turn-buckles or other similar devices which will enable the individual erecting the structure to prestress the cables to the desired extent.

As mentioned, membrane 30 is contoured to form ridges and valleys therein for cooperation with cables 32. The membrane is positioned in the structure with its ridges 33 extending along the diagonals defined by cables 32, so that the membrane is at its highest elevation along these cables. If the membrane is not contoured, the configuration of the cables themselves, and the natural drape of the fabric, will cause ridges or apices to be formed in the membrane. In addition, since cables 32 are suspended at their free ends, the cables will assume an upwardly opening catenary shape when supporting the membrane.

The additional set of cables 34 are secured at their opposed ends 38 to opposed base connectors 22 and are located in the valley 35 formed in membrane 30, between cables 32 and at substantially 90° thereto in the square illustrative embodiment. These cables may be received in sleeves in the fabric in the same way as cables 32, or alternatively, they may simply be placed on top of membrane 30 for frictional engagement therewith. In addition, the free ends 40 of cables 34 may be provided with hooks or other convenient connecting devices for securement to eyelets 42 in base connectors 22.

As with cables 32, cables 34 are preferably supplied in predtermined lengths so that in the completed building these cables cooperate with cables 32 and membrane 30 whereby they are prestressed to the desired extent. Alternatively, these cables may be provided with turn-buckles or similar devices for prestressing the cables as required.

With the relative configuration of the components thus described, it is seen that in the completed construction when cables 32 and 34 are prestressed they cooperate to produce a tensile stress in the membrane. Moreover, all of the components of the structure are operatively interconnected with each other so that they form a three-dimensional space frame of which no part can move without movement of all of the other parts. Specifically, for example, if a superimposed snow load were placed on the structure of FIG. 1, causing membrane 30 and cables 32 to move downwardly, the portions of the membrane in the valleys 35 adjacent cables 34 would tend to move upwardly to compensate for the downward movement of the membrane ridges. However, this movement is resisted by prestressed cables 34 which maintain the valley configuration of the membrane and thus the prestress therein so that the membrane remains relatively rigid. Simultaneously, compressive structure 26 serves to resist the forces in inverted V-shaped structural members 12 which would tend to collapse these structural members inwardly because of their connection to the tensioned cables 32. This structural member therefore equilibrates these forces and maintains the stability of the structure. It is also noted that further structural stability is provided to the structure of the present invention because, as sen in FIG. 2, the various structural components, i.e., cables 32, 34 and rigid structural members 12, 26 are arranged in a triangulated pattern. As a result, all of the forces in the structure are equilibrated and no eccentric moment forces are present therein when the structure is under a load condition.

With the basic arrangement and relation of the components, as described herein, the structure can be designed to a shape and stress so that under any design load case the components will not lose this cooperation with each other. Thus, the tensile members, i.e., the cables and membrane, will always remain in tension and assume the integrity and stability of the structure. Accordingly, the shape of the structure can be controlled to a degree such that membrane 30 will always be maintained in a stressed and relatively rigid configuration while no member of the system will become overstressed.

This principal of cooperating elements provides an extremely flexible building system which can be used to form building structures or shelters having a variety of shapes and patterns and which can be arranged with respect to one another in various ways to achieve complete flexibility in the design, layout and construction.

In a preferred embodiment of the invention the free edges 44 of membrane 30 are secured to edge cables 46 which are tensioned about the legs 16, 18 of the inverted V-shaped structural members 12. These cables may be formed as one-piece members respectively associated with each frame 12 and having their central portion trained over a pulley or the like supported on apex connectors 25 and their free ends secured in any convenient manner to base supports 22. Alternatively, each leg may have a separate cable with its opposite ends operatively connected to the base support 22 and connector 25. In either case, cables 46 are sewn to or otherwise attached to membrane 30 to receive and carry the tensile stresses within the membrane and transfer these forces directly to apex connectors 25 and base supports 22 so that legs 16, 18 are subjected only to compressive stresses, with no possibility of a moment force or eccentric stress being applied thereto. As a result, legs 16 and 18 can have a smaller diameter than would be necessary if the membrane were connected directly to them. The remaining portion 48 of the membrane 30, between cables 46 and legs 16, 18 are thereby free of stress and can simply be attached to the legs by hook and eye arrangements or other convenient connecting mechanisms.

The principles involved in the construction of the preferred embodiment of FIG. 1 can be utilized to form a variety of shaped structures having prestressed cables utilized to support a flexible membrane between relatively rigid support members. In particular, the triangular support members 12 can be arrayed in substantially any desired configuration to form a closed polygonal structure. Where an irregular polygon is utilized, and there are no directly opposed structural members as in the regular polygon or square illustrated in FIG. 2, ridge cables 32 can be each connected at one end to an associated frame apex 20 and at their opposed ends to a central tension ring so that each of the apices of the inverted V-shaped members 12 are interconnected by tensile members in a similar manner to that of the structure illustrated in FIG. 2. Similarly, the set of cables 34, in the valleys of the membrane, would be connected to the same or a complementary tension ring. In each case, membrane 30 would be contoured or folded to have ridges and valleys, with the ridges being located at the location of the cables 32 and the valleys being therebetween and having cables 34 located therein in order to maintain the membrane under stress. Of course, a compression structural member corresponding to the member 26 would also operatively interconnect the apices of the members 12 in order to resist the tensile forces in the membrane which would tend to draw or collapse the structural members 12 inwardly with respect to the building.

In addition, it is noted that although the illustrative embodiment of the present invention illustrates the structural members 12 being positioned in a directly vertical configuration, it is contemplated that these members may be inclined outwardly or inwardly of the building as desired for the particular use intended. The only variant would then be the stresses required in the cables in order to maintain tension in the membrane 30 under predetermined load conditions. Further, in this case, apices 20 of the structural members also would be connected by a compressive structural member corresponding to member 26 to resist and equilibrate the inwardly directed forces applied to frame members 12.

In summary, the rigidity of the final structure is produced by means of prestressing the tension cables in the building. The set of cables 32, which assume the shape of an upwardly opening curve, support the flexible membrane thereon while the other set of cables 34, which are placed to define a downwardly opening curve (generally paraboloid as seen in FIG. 3) serve to tension membrane 30 against cables 32 to prestress the membrane thereby causing it to be relatively rigid. Moreover, these cables serve to resist windloads which would tend to lift the flexible membrane.

The tensile forces in the cables and membranes are distributed to the inverted V-shaped structural members 12 and these forces are equilibrated to render the building stable by the compression structure 26 interconnecting the apices of the various members 12. By thus putting all of the components of the structure under stress, and interconnecting them with each other into a three dimensional space frame structure of which no part moves without the other, the structure can be shaped and stressed so that under any load condition the components will not lose their cooperation with each other and the tensile members will remain in tension. Similarly, the compression structure 26 will always remain in compression under loads applied to shelters, so that the tensile loads in the shelter and the remaining structural members of the building will alsays be equilibrated.

Referring now to FIG. 4 of the drawing, there is illustrated another embodiment of the invention wherein six inverted V-shaped members 12 are utilized. In this embodiment, members 12 are tilted slightly towards the center of the building rather than being placed in a directly vertical configuration as in FIG. 1. In this case membrane 62 utilized therein conforms in plan to the polygonal shape defined by structural members 12, when viewed in plan. Moreover, membrane 62 is contoured, as described above, to have ridges 64 and valleys 66 therebetween.

A first set of cables 68 corresponding to cables 32 of the prior embodiment has respective cables thereof located and secured to the membrane between the apices 20 of structural members 12. Similarly, a second set of cables 70, corresponding to cables 34 of the prior embodiment, has respective cables therein positioned in the valleys 66 between ridges 64 and cables 68. These cables are secured to base support members 22 in order to prestress membrane 62 against cables 68 to form a relatively rigid and stable construction in the manner similar to that described above. In addition, the apices of structural members 12 are interconnected by a compression member 74 which operatively interconnects each of the apices.

Alternatively, structural members 12, in the embodiment of FIG. 4, can be placed in a generally vertical position and will assume a hexagonal outline, as indicated by the phantom lines 76 in the drawing. In this case membrane 62 would be enlarged to conform to the outline of hexagon 76, with ridges 64 extending outwardly to the periphery of the polygon. Compression member 74 would necessarily be made somewhat larger to interconnect the apices of the members 12, which apices are now further from the center than in the embodiment illustrated in solid lines in FIG. 4.

As a result, it is seen that the structure of the present invention requires no external support for the building even though a flexible membrane is used to form the shelter portion thereof. This, therefore, is substantially different than previously proposed movable or temporary shelters such as tents. The structure is made of relatively lightweight structural elements which are repetitive in size and therefore quite suitable for mass production operations. In addition, the fabric utilized is flexible and can be folded into a small package with the cables associated therewith rolled into rings for transportation.

Such shelters or structures can be erected relatively rapidly and inexpensively at an emergency site to provide temporary shelters or transported and used by an individual or family as a temporary vacation home and shelter. However, because the structure is relatively rigid, it can be conveniently converted into a semi-permanent or permanent housing unit. This can be done by the provision of modular interior components providing sanitary facilities and individual rooms, floors and ceilings. In addition, because of the regular peripheral configuration of the structure a number of structures can be placed together in a variety of arrays or patterns to provide a pleasing and functional appearance.

Although illustrative embodiments of the present invention have been described herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of this invention.

What is claimed is:

1. A shelter structure comprising, a plurality of rigid inverted V-shaped structural members positioned in a predetermined array forming a closed polygon when viewed in plan, a relatively rigid compression member operatively interconnecting the apices of each of said inverted V-shaped structural members, a flexible membrane operatively associated with said frame members and conforming in plan to said closed polygon, a first set of prestressed tension members operatively connected to the apices of said inverted V-shaped members for supporting said flexible membrane, and a second set of prestressed tension members secured to said inverted V-shaped frame members and operatively associated with said membrane, said second set of tension members being located in predetermined positions between said first set of tension members to maintain said membrane in tension under substantially all load conditions, whereby said first and second sets of prestressed tension members cooperate with each other and with said flexible membrane to form a relatively rigid and stable structure.

2. The structure as defined in claim 1 wherein said first and second sets of prestressed tension members each comprises a plurality of flexible cables, said first set of cables supporting said membrane in a folded configuration having ridges in which said first set of cables are located to support said membrane, and valleys therebetween.

3. The structure as defined in claim 2 wherein said second set of cables are positioned with at least one cable located in each of said valleys.

4. The structure as defined in claim 3 wherein said flexible membrane is formed with a contoured configuration to assume said ridge and valley configuration when supported on said first set of cables and conform in plan to said polygon.

5. The structure as defined in claim 4 wherein said inverted V-shaped frame members are arranged to form an equilateral closed polygon when viewed in plan.

6. The structure as defined in claim 5 comprising four of said inverted V-shaped members positioned to form a square when viewed in plan.

7. The structure as defined in claim 4 wherein said compression member comprises a closed rigid member when viewed in plan, said closed rigid member being secured adjacent its periphery to the apices of each of said inverted V-shaped frame members.

8. The structure as defined in claim 4 wherein said first set of cables are secured to said frame members to define generally upwardly opening curve segments and said second set of cables are secured to said frame members to define generally downwardly opening curves.

9. The structure as defined in claim 4 wherein the free ends of said inverted V-shaped members are operatively secured to a common base support.

10. The structure as defined in claim 4 including a third set of cables operatively secured to said membrane, said cables being respectively associated with the legs of said inverted V-shaped frame members and having their free ends operatively connected to the opposite ends of their associated leg to transmit tensile forces in said membrane to the ends of said legs.

11. The structure as defined in claim 8 wherein the cables in each of said first and second sets are operatively connected at their opposed ends to said frame members, the cables in said first set being connected between opposed apices of opposed frame members and the cables in said second set being connected at their opposed ends adjacent the free ends of opposed inverted V-shaped frame members.

12. A shelter structure comprising a plurality of inverted V-shaped rigid frame members positioned in a predetermined array, a flexible membrane operatively associated with said frame members and contoured to form ridges therein extending between the apices of said rigid frame members and valleys between said ridges, a first set of prestressed cables operatively connected between the apices of said frame members and supporting said flexible membranes along said ridges, a second set of prestressed cables operatively associated with said membrane and said frame members with at least one cable in said second set being located in said of said valleys and a rigid compression member interconnecting the apices of said inverted V-shaped frame members whereby said first and second sets of prestressed cables cooperate with each other and with said membrane to prestress said membrane and form a relatively rigid structure.

13. A shelter structure comprising four inverted V-shaped rigid frame members positioned on a common support in an array forming a square when viewed in plan, a flexible membrane operatively associated with said frame members and contoured to form ridges therein extending along the two diagonals of said square between opposed apices of said frame members and valleys between said ridges, a first pair of pre-

stressed tension cables being respectively connected between the apices of opposed frame members and along said diagonals, said first pair of cables being operatively connected to said membrane to support said membrane along said ridges, a second pair of prestressed tension cables respectively located in the valleys between said first set of cables and said ridges at approximately 90° with respect to each other and operatively connected to said inverted V-shaped members adjacent the free ends thereof, and a rigid compression member interconnecting the apices of said inverted V-shaped frame members whereby said first and second pairs of prestressed cables cooperate with each other and with said membrane to prestress said membrane and form, with said frame members, a relatively rigid self-supporting structure.

14. The structure as defined in claim **13** wherein said first pairs of cables are suspended between their associated apices and assume the shape of a catenary and said second pair of cables, in cooperation with said membrane, assume a shape corresponding substantially to downwardly opening parabolas.

15. The structure as defined in claim **14** wherein said rigid compression member comprises a generally square rigid frame when viewed in plan, having each of its corners respectively connected to the apices of said inverted V-shaped frame member.

16. The structure as defined in claim **13** wherein the free ends of each of said inverted V-shaped frame members are operatively secured to a common support.

17. The structure as defined in claim **15** including a plurality of edge cables wherein each of said edge cables is respectively associated with an adjacent leg of said inverted V-shaped frame members and operatively secured to said flexible membrane, said edge cables having free ends operatively connected to the opposite ends of their associated leg, thereby to transmit tensile forces in said membrane to the ends of said legs.

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